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Reconstructive upper limb surgery in patients with cervical spinal cord injury

Evaluation of postoperative treatments and examination of applicability of the Klein-Bell ADL Scale

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RECONSTRUCTIVE UPPER LIMB SURGERY IN PATIENTS WITH CERVICAL SPINAL CORD INJURY

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The patient in the picture on the front cover has given his verbal consent to the author to publish the picture where he can be identified

Reconstructive arm and hand surgery in patients with cervical spinal cord injury; Evaluation of postoperative treatments and examination of applicability of the Klein-Bell ADL Scale

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ABSTRACT

Aims: Studies I & II: To describe and evaluate postoperative deltoid-triceps protection of tendon elongation and long-term clinical follow-up after tenodesis to the IP joint of the thumb. Study III: To examine and explore the applicability of the Klein-Bell ADL Scale (K-B Scale) in patients with cervical spinal cord injury in terms of daily activities and the association between basic ADL and upper extremity function.
Method: Studies I & II data were collected retrospectively. Eleven patients were included in study I. The patients were divided postoperatively into two groups; patients using their manual wheelchair without a special armrest and patients using an electric power driven wheelchair with a special armrest. Stainless steel sutures (markers) were placed proximally and distally of the tendon-to-tendon attachment sites. The distances between markers were measured via upper extremity x-ray to evaluate tendon elongations. Thirty-three patients were included in study II. Extension, flexion and range of motion were measured to evaluate how the tenodesis of the IP joint of the thumb influenced the different movement modalities of the IP joint of the thumb. Study III: Data were collected prospectively. Fifty-five patients were included in the study. Assessments of the patients' independence were made according to the K-B Scale. Three more analyses were performed; the first analysis was made to examine whether assistive devices and car and house adaptations could influence the patient's independence. The last two analyses included investigations of whether arm and different grip functions and different grip phases could be detected in the items' operational criteria.
Results: In study I the total distances between markers after reconstruction of deltoid to triceps were significantly lower in the patients using an electric power driven wheelchair with special armrest compared to those without the armrest. The largest difference in tendon elongation between the groups occurred in the proximal tendon transfer. Elbow extension deficit was decreased in the group using the electric power wheelchair with an armrest, although not significantly as compared to those without the armrest. In study II treatment with a thumb splint after tenodesis to the IP joint of the thumb gave a pliable and well balanced IP joint with comparable results in extension, flexion and ROM at six months and 12 months postoperatively. In study III only the raw sum score and not the weight scheme in the K-B scale discriminated the patient's independence in daily activities (ADL). Assistive devices and car and house adaptations made the patients more independent. Lack of grip function decreased the patient's ability to become independent.
Conclusion: The use of an electric power driven chair with a special armrest and thumb splint has shown that relatively simple adjuncts can positively influence the effectiveness of operations performed. The cooperation between the hand surgeons and the therapist to develop these treatments has been important for improved results in these studies. The K-B Scale can be used to assess basic ADL and can discriminate between cervical SCI patients' independence in ADL. To become a useful tool, the K-B Scale's structural properties in conjunction with arm and grip function must be further investigated.

Key words: tetraplegia, tendon transfer, reconstructive hand surgery, Klein-Bell ADL Scale, outcome measurement, ADL

ABBREVIATIONS

ADL	Activities of Daily Living
ASIA	American Spinal Injury Association
BADL	Basic Activities of Daily Living
CAT	Computer Adaptive testing
EPL	Extensor Pollicis Longus
FPL	Flexor Pollicis Longus
FIM	Functional Independence Measure
ICF	International Classification of Functioning, Disability and Health
IC	International Classification of Hand Surgery
IP	Interphalangeal joint
K-B Scale	Klein-Bell ADL Scale
MMT	Manual Muscle Test
MRC	British Medical Research Council
O	Ocular impulses; depends on vision
OCu	OculoCutaneous impulses; both vision and tactile gnosis.
ROM	Range of Motion
SCI	Spinal Cord Injury
SCIM	Spinal Cord Independence Measure
QIF	Quadraplegia Index of Function
UEMS	Upper Extremity Motor Score
2PD	Two Point Discrimination

CONTENTS

LIST OF INCLUDED PAPERS

This thesis is based on the following three papers, which will be referred to in text by Roman numerals:

Paper I:
Friden J, Ejeskar A, Dahlgren A, Lieber RL. Protection of the deltoid to triceps tendon transfer repair sites. J Hand Surg [Am] 2000; 25(1):144-9.

Paper II:
Ejeskar A, Dahlgren A, Friden J. Split distal flexor pollicis longus tenodesis: long-term results. Scand J Plast Reconstr Surg Hand Surg: 2002;36(2):96-9.

Paper III:
Dahlgren A, Karlsson AK, Lundgren-Nilsson A, Friden J, Claesson L. Activity performance and upper extremity function in cervical spinal cord injury patients according to the Klein-Bell ADL Scale. Spinal Cord:. 2007:Jul;45(7):475-84.

INTRODUCTION

Epidemiology - Spinal cord injuries

In Sweden the incidence of traumatic spinal cord injuries (SCI) is approximately ten to 15 cases per million inhabitants per year. Thus, about 120 persons sustain a traumatic SCI every year in Sweden (1). Internationally and nationally the mean age at injury has risen during the last years and is now reported to be over 30 years (1, 2). More men (70-80%) than women sustain a traumatic SCI. However, the proportion of women sustaining a traumatic SCI has increased in recent years. Approximately 50% of all traumatic SCI affects the cervical portion of the spinal cord (1).

Consequences of SCI

A spinal cord injury (SCI) instantly changes a person's life forever (3). The consequences of the injury are reflected in the extent of loss of motor and sensory function and the resulting inability to perform activities of daily living (ADL) (4). Important prerequisites for ADL are upper extremity function (5-7) and physical capacity (8). Other important factors are age, gender, body mass (9), physical fitness (7, 9), motivation, psychosocial status, medical complications (7) and socio-cultural background (10). In many cervical SCI patients, the level and the extent of the lesion have a great impact on arm and hand function. The rehabilitation of the upper extremities is thus of the utmost importance, and the therapist's aim is to maintain flexible, supple hands that are free from deformity. Rehabilitation can be divided into three different phases, the acute, the subacute and the reconstructive (restorative) phases (11, 12). Conservatively this could be achieved by maximising the individual's function through strengthening voluntary upper extremity muscles, using splints to position and preserve arm and hand function, and training activities of daily living (ADL), including the prescription of assistive devices (13).

Rehabilitation

Rehabilitation after a SCI is a lifelong process that requires a reorientation toward nearly every aspect of daily life (14). Rehabilitation is defined as the management of disease consequences, which include impairment, functional limitation and disability (15). The goals in rehabilitation that uses a multidisciplinary approach are to reduce symptoms, restore, substitute, and modify function to minimize disability, and ultimately to return the patient to the community (15, 16). Clinically, rehabilitation can be seen as a learning process, aimed at the acquisition of novel skills or the reacquisition of old skills, with its main goal being to regain optimal functional independence (17).

Measurement, Assessment and Evaluation

In rehabilitation, a functional assessment is a decision process that results from the interaction between diagnostic classification and measures that aim to recognize, anticipate or modify the interaction between the disabled person and his environment (18). Measurement is a process of assigning numbers according to a set of specified rules (19) to represent quantities of a trait, attribute or characteristic, or to classify objects (20, 21). The numbers are results of the measurement and are used to understand and describe aspects of function, abilities or personal characteristics, but not the persons themselves (21). The rules are important concept of the measurement procedure because they determine the quality of the measurement. The measurement procedures are however the same, regardless of whether the measurement is a directly observed property or whether the rater's must measure indicators of properties (22).

A variable is a measurable dimension of a concept and can be translated by means of an operational definition into four basic levels of measurement: nominal, ordinal, interval and ratio levels, where the ratio level is the highest level (23, 24). Thus, the statistical operations that are permissible depend on the measurement level of the data collected (24). Tools used to measure outcome must be reliable, valid and discriminative. Outcome may be specified in a variety of levels, including disease, impairment, activity or participation (25). When selecting a specific measurement or overall measurement strategy it is important to consider the purpose why the measurement information is gathered, how the results or the measurement might be analysed and used. To measure an individual, measurements can be placed into four main groups: evaluative, descriptive, predictive and discriminative. These are issues to consider when reviewing a measurement in terms of the purpose of the study. It is important when examining a measure's discriminative ability to ensure that the chosen outcome measure is able to differentiate within the patient group and that it identifies meaningful differences in a patient's abilities (26).

Evaluation in occupational therapy

An occupational therapy evaluation should assess components of health, including body structure/body function. However, this focus on body structure/body function is only appropriate as long as the assessment of abilities is related to how these abilities interact with the environment and daily activities to create activity limitations. The ultimate goal to understand body structure/body function is to determine the way in which the person's abilities may be enhanced, activities modified or the environment adapted to improve the person's participation in daily life (27, 28).

Evaluation of people's functional ability, especially their performance in ADL, is one of the oldest and most common methods of measuring severity of disability and outcome of different interventions for disabling conditions (29, 30). It is important to determine a standardised instrument development method, the psychometric properties of the instrument (21) and the area in which it will be used (31) before evaluation. However, assessment of

ADL is accepted as an essential part of outcome research (32) and it offers a simple and feasible method for discriminating, predicting or evaluating patients' functional outcome (33).

An important part of occupational therapy evaluation is ADL, where the purpose is to determine present and potential levels of functional ability in SCI patients (14). To do this the therapist must learn about the patients, their repertoire of activities, and any difficulties they have in performing the activities they need, want, or are expected to do (34). The ability to perform different everyday tasks in ordinary life is integrated with environmental demands (physical, social and cultural) and individual capacity, interest and motivation (35). Conceptually, ADL could apply to all tasks an individual routinely performs (36). However, the term ADL is generally restricted to tasks involving functional mobility and personal care. Basic ADL (BADL) is a very personal part of every person's daily routines. The term BADL is synonymous with self-care. It includes mobility, feeding, grooming, dressing, bathing, and personal hygiene and toileting. These tasks are necessary to maintain health and are universal (37).

Evaluation in reconstructive hand surgery

Although earlier studies (38, 39) have shown that reconstructive arm and hand surgery can influence patients' level of activity, the outcome of reconstructive hand surgery has hitherto been focused on evaluation at the impairment level (40) (e.g. range of motion, grip strength, cutaneous sensation, dexterity) (41, 42) rather than on the activity level. However, the activity domain cannot be inferred from the underlying impairment itself; it must be measured with appropriate scales (43). The activity domain in the International Classification of Functioning, Disability and Health (ICF) (40) envisions human activities as the purposeful, integrated use of body functions. This approach might be used to better understand the link between demands for arm and hand function and performance in basic ADL (44).

Arm and hand function vis à vis ADL

Individuals with cervical SCI injuries vary largely in residual motor and sensory function (16, 45). Spasticity is a common secondary condition in cervical SCI and can limit range of motion, cause pain and/or cause additional stress to muscles and joints. Typically, spasticity can interfere with various body functions such as hand and upper limb control and has been reported to significantly impact activities of daily living (46). Besides the loss of hand function the patient also suffers from instability in the trunk. This loss of function influences the patient's performance in ADL that require sitting balance (16), pushing-up motion, trunk support (47), reaching (6, 47), and grasping and holding objects (16, 48). Even the most basic ADL tasks can become a challenge and can render the individual dependent upon assistance in many areas of daily living (3, 49). The ability to perform

ADL ranges from total dependence to total independence in ADL in patients with different levels of cervical injuries (16, 50). Earlier studies (6, 51) have suggested that C6 and C7 are critical levels for achieving independence in daily activities. More recent studies (52, 53) have shown that the ability to transfer is decisive in the process of gaining independence in ADL.

An important potential improvement in function and independence in cervical SCI patients lies in a proper rehabilitation of the upper extremities. The level of independence among these patients relies heavily on their ability to use the upper extremities in daily activities. Activities such as feeding, dressing, bathing, making transfers and propelling a wheelchair require the ability to use the arm and hand in purposeful and precise movements (54). The first two phases in upper extremity rehabilitation, acute and subacute, are aimed at preventing complications, achieving optimal functioning within the limits of the neurologic deficit (55-57) and creating optimal conditions for the reconstructive (restorative) phase (12, 58).

Reconstructive arm & hand surgery

Reconstructive arm and hand surgery requires an understanding of anatomy, physiology, biomechanics of human upper muscles, healing and adhesion formation to restore tendon gliding and digital joint motion (59). It is an alternative for individuals with higher cervical lesions to restore motor function and regain the functional levels related to the ability to perform self-care (60-62). Earlier studies have shown that most patients with cervical SCI prefer recovery of hand function to that of bladder, bowel or even sexual function (63, 64). Even though regaining arm and hand function is of the highest priority among these individuals, reconstructive hand surgery is not a common procedure at many SCI units (39). During the surgery planning process the key factor is to be client-centered (65). This means to incorporate the patient’s needs, expectations and priorities (66), to set realistic goals (65) and to identify the best surgical options to provide the most functional outcome (13). A tendon transfer is a surgical procedure in which the tendon of normally functioning muscle is detached or split and reattached to a non-functional paralysed muscle to substitute or enhance function (50). The architectural properties of the donor muscle should be matched to the original muscle’s force and excursion potentials. However, many other factors also influence donor muscle selection, including donor muscle availability and morbidity, the donor muscle’s preoperative strength, integrity and expendability, possible patterns of synergism, transfer route and direction for the donor muscle (67). The retraining period after surgery may be a long and tedious undertaking that requires close collaboration between the surgeon, therapist and patient (68). A high degree of patient motivation must be established to insure proper participation in the demanding postoperative regimen associated with these procedures (68). The postoperative training program must therefore be carefully planned on the basis of the unique status of each patient (69). The ultimate functional outcome is a transfer in conjunction with other procedures such as tenodesis and joint stabilisation to generate maximal strength at a desired joint angle (70) in order to enhance the patient's possibilities to use the newly acquired arm and grip functions in daily activities (71).

Reconstruction of elbow extensor

Elbow extension is required not only to extend against gravity but to adequately position the hand for activities of daily living (72). Although gravity may assist elbow extension, it may also cause it to buckle, allowing the hand to suddenly strike the face or forehead (73). Many patients with cervical SCI lack active control of elbow extension and therefore have reduced upper extremity strength and stability (72, 74), which influences their ability for weight shift manoeuvres, wheelchair propulsion and daily activities requiring reaching movements (6, 52, 75). The posterior deltoid muscle is the most commonly used transfer to restore voluntary elbow extension (76, 77). Restoration of triceps function through posterior deltoid tendon transfer has been shown to influence not only the elbow but also the shoulder during free movements of the upper limb (78). However this transfer can only generate approximately 20% of the force of the normal triceps (72). Thus, while the transfer is adequate for antigravity movements and positioning in front of, above, and at chest level for reach and grasp abilities, it would not suffice for wheelchair transfer, which demands a high force of elbow extension manoeuvres (72). Triceps reconstruction has been termed the "fundamental intervention" (79) not only for objective improvements (78, 80) and subjective functional benefits in daily life (39, 42, 73) but also because it improves the function of distal tendon transfer, especially those utilising the brachioradialis as a donor muscle (81, 82).

Earlier studies (83, 84) have reported that the transfer of the posterior deltoid to the triceps tendon provides adequate strength and excursion for elbow extension in patients with cervical SCI. The muscle-tendon units are set at a strong passive tension when the posterior deltoid is used as the donor muscle to reconstruct elbow extension. This depends partly on the necessity of the reconstructed elbow extensor being able to extend against gravity and partly on the antagonist, the biceps muscle, which is normally very strong. Thus, this procedure puts the structural integrity of the tendon grafts at risk for overstretching during the immobilisation and rehabilitation period (70). Clinically, without any general restriction in the treatment regimen after reconstruction of elbow extension, the tendon grafts often become elongated. If the tendon junction was elongated more than 20 mm it would clinically result in a lack of full active extension of the elbow as well as weak elbow extension power (72). It was believed that unrestricted daily life together with wheelchair mobility had a negative effect after reconstruction elbow extension. Hence, the postoperative regimen was altered after 1993 to protect the tendon grafts from excessive tension and elongation.

Grip reconstruction

Early active mobilisation or controlled active motion after flexor tendon repairs decreases adhesion formation, increases joint range of motion, improves repair site strength and enhances functional recovery (85-88). Over the last decades the use of active motion protocols has improved functional results after flexor tendon injuries and is now the standard of care in flexor tendon rehabilitation (89). It was believed that an improved range of motion, and thereby increased power control, would be obtained by reducing the amount of adhesion following tendon surgery (90). The treatment protocol includes passive motion of the finger flexors by extending fingers actively combined with passive flexion (89). However, since the attachment site in tendon transfer surgery is generally firmer and has less risk of rupture because of the significant tendon-to-tendon overlap (91), a new treatment regimen was introduced in 1999. The rehabilitation strategy focuses on retraining the donor muscles with high tendon excursion and low tendon force (92) and, over time, progressively increase wrist extension together with a slow increase of tendon load (93, 94). In contrast to flexor tendon rehabilitation (89), functional retraining after grip reconstruction includes both passive and active motion with restricted and controlled finger and thumb flexion, allowed the day after surgery. The patient uses new movement strategies to identify the donor muscles, which in turn assist the patient to mimic the original motion of the donor muscle. To get the best possible recruitment pattern of muscle activation, the patient uses sensory feedback during the retraining period (95). The patients use the best of their senses in relation to their level of injury; this might involve vision, sensibility and hearing or a combination of all senses.

Splints are used during training to maximize a safe zone for tendon excursion (96) and during rest to prevent extensive stretching in the tendon transfers and postoperative edema (91). During the first training period the patient focuses on relearning the movement pattern of the donor muscles with an individually tailored training program; during the second training period the focus shifts towards reintegrating the new grip functions in daily activity.

Reconstruction of active thumb flexion in the absence of control of the active thenar muscles will lead to full active flexion in the interphalangeal (IP) joint. The surface area is reduced since the tip, and not the pulp, of the thumb is applied to the radial side of the index finger (97). In conjunction with grip reconstruction, a new procedure was introduced by the split flexor pollicis longus (FPL) to the extensor pollicis longus (EPL) tenodesis, which creates a functional grip in the thumb. This new technique offered a more optimal contact surface between the pulp of the thumb and the radial aspect of the index finger without fusion of the IP joint of the thumb. The split tenodesis stabilises the IP joint and allows for 30-40° of active flexion (97).

The complexity of human behaviour and clinical phenomena present a considerable challenge to the researcher. To build a scientific understanding of the clinical problems concerning the postoperative regimen after reconstruction, elbow extension and thumb flexion and assessments of ADL in cervical SCI patients in connection with reconstructive arm and surgery must be studied, analysed and the results integrated into clinical practice.

AIM OF THE STUDY

The general aim of this thesis was to evaluate intervention in relation to postoperative treatment after reconstructive arm and hand surgery in patients with injuries and diseases in the cervical spinal cord. A further aim was to examine the applicability of an ADL instrument and the association between basic ADL and upper extremity function.

Specific aims

1. To describe and evaluate the postoperative deltoid-triceps protection of tendon elongation as measured by the stainless steel markers technique (study I)

2. To describe and evaluate the long-term clinical follow-up after tenodesis to the IP joint of the thumb (study II).

3. To examine and explore the applicability of the Klein-Bell ADL Scale in patients with cervical spinal cord injury in terms of daily activities and the association between basic ADL and upper extremity function (study III).

MATERIAL AND METHODS

Study group

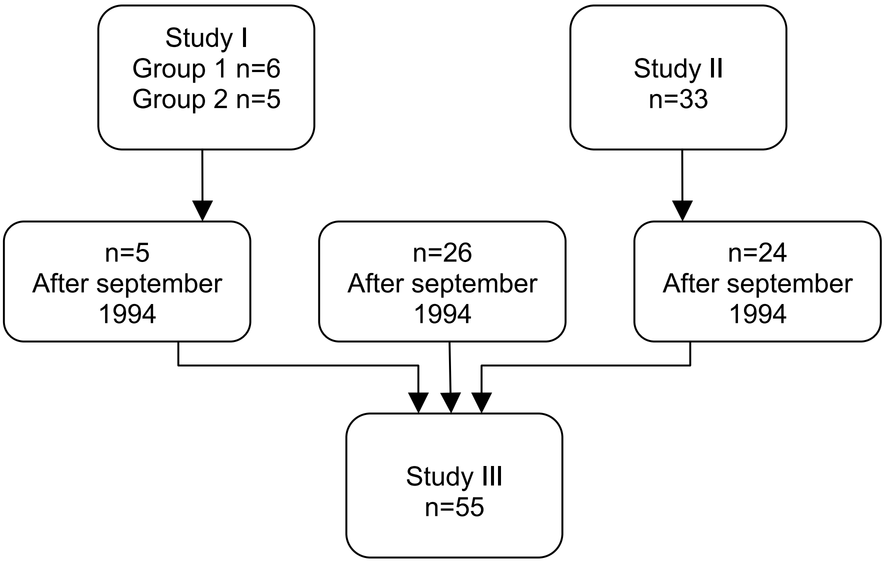

Figure 1. Flowchart describing the patient's participation in study I to III.

The inclusion criterion in all three studies was persons with traumatic cervical spinal cord injuries. Study II also included one patient with Guillain-Barré paralysis and study III also included patients with acute vascular injury in the cervical level of the spinal cord. The patients in study III had no prior reconstructive hand surgery before September 1994 (figure 1).

Demographic data concerning age, gender were collected in studies I and III. Time since injury were collected in studies I and III and cause of injury in study I. Preoperative evaluations were made in studies I and III and consisted of a sensibility test, joint range of motion (ROM) test and muscle strength test. The International Classification of Hand Surgery (IC) (98) was used to classify the patient's arm and hand function in studies I and II (Table 1). In study III the patients were classify according to the American Spinal Injury Association (ASIA) (4). In study III the data concerning the patient's civil status and their ambulatory function was collected. Sensory function was measured using two-point discrimination (2PD) (99), and ROM was measured (100). The manual muscle test (MMT) followed the British Medical Research Council (MRC) (101).

Table 1. Motor components in International Classification of Hand Surgery in Tetraplegia (IC)

Sensibility O or OCu Group	Motor characteristics Lowest muscle grade ≥ 4	Description Motor function
0	No muscle below elbow	Flexion and supination of elbow
1	Brachioradialis	Flexion and rotation to neutral position of forearm
2	Extensor carpi radialis longus	Extension of wrist (weak)
3	Extensor carpi radialis brevis	Extension of wrist (strong)
4	Pronator	Pronation of forearm
5	Flexor carpi radialis	Flexion of wrist
6	Finger extensors	Extrinsic extension of digits
7	Thumb extensors	Extrinsic extension of thumb
8	Partial digital flexors	Extrinsic flexion of fingers (weak)
9	Lack only intrinsic	Extrinsic flexion of fingers
10 =X	Exceptions	

Footnote: Group denotes number of muscles with minimum grade 4 (MRC). O= Ocular impulses - depends on vision for sensory impulses and OCu= oculocutaneous impulses – depends on both vision and tactile gnosis for sensory impulses.

Ethical approval

Study I and study II were considered to be quality assessments of clinical treatment and ethical approval was thus not applied for. Study III was approved by the Ethics Committee at Göteborg University Dnr 377-06. Informed consent was obtained after verbal information was given to the patients.

Study I

Patient population

This study was a retrospective study and data were collected before and after the treatment with an electric power wheelchair and a special armrest was introduced after 1993. The study consisted of 11 patients with cervical SCI (mean age 24 years; age range 20-35 years; 9 men and 2 women) in whom 13 tendon transfers of the posterior deltoid to triceps brachii muscle were performed. The average time between the time of injury and the procedure was 3.5 ± 1.0 years. The patients upper extremity function ranged from O:0 to OCu8 according to the IC (Table 1). The group was divided into two groups; the first group did not use armrest support (nonrestricted group) (n=6) and the second group (n=5) used armrest support (restricted group).

Surgery procedure – elbow extension

During surgery the posterior deltoid border was identified and separated from the middle posterior deltoid. The posterior deltoid insertion was then identified and subsequently detached along with the associated periosteum. A tendon was harvested from the tibialis anterior muscle to be used as a tendon graft between the posterior deltoid and the distal triceps tendon. The distal deltoid tendon and the tendon graft were sutured with an overlap of 5 cm along the sides of the graft and the host tendons. The distal graft insertion was created by threading the tendon graft through several holes made in the flat triceps tendon (Figure 2).

Figure 2. Operative technique. (a) Reconstruction of elbow extension with separation of posterior deltoid. (b) Attachment of the tibialis anterior to posterior deltoid.(c) Preparation for tunnelling tendon graft to insertion into the triceps tendon.

The muscle-tendon unit passive tension was set to a moderate level when the arm was positioned along the body with the elbow extended.

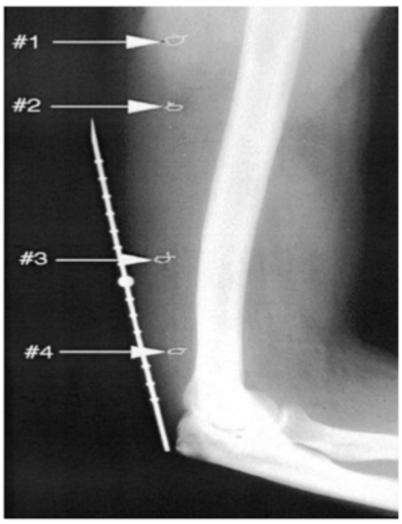

Figure 3 . Conventional lateral x-ray view of the upper arm. Four stainless steel markers are indicated. The distances are denoted as proximal (#1 and #2) and distal (#3 and #4) as described in the text. A calibration rule is shown at the left of the figure.

Stainless steel sutures were place in four positions the deltoid tendon (marker #1), proximal tendon graft (marker #2), distal tendon graft (marker #3) and triceps tendon (marker

#4), at a spacing of 3 cm (Figure 3). All patients (n=11) were treated with a circumferential plaster with the elbow flexed 10° to 15° (Figure 4).

Figure 4. (a) The patient was immobilized for 4 weeks in a circumferential plaster. (b) A static splint was thereafter used during the night. (c) An adjustable orthosis during the day.

Postoperative treatment

Plaster cast immobilization was maintained for four weeks to permit adequate strength recovery of the surgical sites of the tendon transfer (Figure 4). An adjustable elbow orthosis was applied and used for eight weeks of postoperative training (figure 4). The angle of the orthosis was changed by 10° every second week to allow additional elbow flexion (102, 103). During sleep, a static splint (Figure 4) was used and the arm was positioned slightly abducted.

Six patients used their manual wheelchair and were only provided with adjustable elbow orthosis during the day and a static splint during the night. Five patients had, apart from the adjustable elbow orthosis during the day and a static splint during the night, also been provided with a specially designed armrest. The armrest consisted of a semicircular and partially constrained padded splint support. It was mounted on an electric power driven wheelchair and aligned along the side of the trunk. Thus, the shoulder joint adduction was effectively prevented (Figure 5). All personal transfers were not allowed until three months postoperatively (120).

Figure 5. (a) The arm support attached to the electric power driven wheelchair. (b) Not only is the elbow motion restricted, the shoulder is also restricted from being adducted.

Postoperative evaluation

Upper extremity x-rays were obtained four to six weeks, three months and six months after surgery. In some cases, measurements were obtained up to two years after surgery. The hand surgeons were responsible for the MMT test, the 2PD test, the IC and the measurement of range of motion.

The distances between markers 1 and 2 (defined as the proximal interval) and 3 and 4 (defined as the distal interval) were measured after adjusting for x-ray magnification using a calibration ruler (Figure 3). After surgery, elbow extension was measured with a goniometer with the arm maximally elevated while the patients were seated in a wheelchair. The difference between maximal active and maximal passive extension was measured and reported as elbow extension deficit (in degrees).

Study II

Patient population

This was a retrospective study and data were collected from 1995 to 2000. The study group consisted of 33 patients, 32 with cervical SCI and one patient with a Guillain-Barré paralysis. Seven patients operated both hands while 33 patients were reconstructed in one hand: in total 40 hands. In this study the patients' arm and hand function were classified according to IC (98). The classification showed that 35 arms (88%) ranged from O:0 to OCu8, and five arms (12%) were classified as group X (exception) and subdivided into the most similar standard group.

Thirty-three patients were included in the study; however one patient lacked data altogether in one of two hands at both at six months and 12 months. Thus 39 were hands included in the analysis. Thirty-two patients were included in the follow-up at six months. Two patients lacked data in one of two operated hands. Data were available in a total of 37 hands for follow-up at six months. At 12 months, 20 patients were included in the follow-up. Five patients were operated in both hands which meant that data were available in 25 hands for follow-up at 12 months.

Data from the six-month follow-up concerning flexion, extension and range of motion (ROM) were investigated because of the missing data (n=15) at the 12-month follow-up. The data were divided into two groups; the first group included patients who lacked data at 12 months (n=15) and the second group (n=22) included patients who had data at 12 months. The purpose here was to investigate whether the data at the six-month follow-up could support previous findings that the split tenodesis gave pliable thumb joint with a ROM of approximately 30°.

Active flexion, active extension and passive flexion were measured in the thumbs' IP joint (in degrees). The ROM was calculated as the difference between active flexion and active extension. The hand surgeons were responsible for the IC and the measurement of range of motion.

Surgery procedure – Tenodesis of the IP joint of the thumb (Split Tenodesis)

The aim of split-tenodesis technique is to equalise the pull on the volar and dorsal aspects of the IP joint, stabilising it during thumb flexion (97). During the procedure the distal part of the FPL is exposed and divided longitudinally and the radial half is detached from the distal phalanx. The detached tendon is rerouted radially and dorsally and is sutured to the long extensor tendon of the thumb (Figure 6). The degree of tension is tested at the wrist level and should preferably result in 20°-30° of flexion in the IP joint.

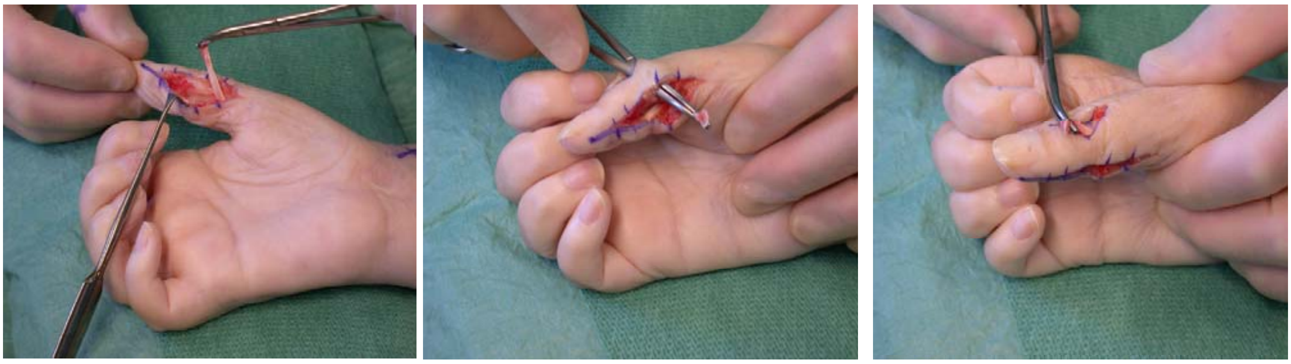

Figure 6. Operative technique. (a) The FPL tendon is split longitudinally and (b) the radial half is detached from its insertion and rerouted dorsally, (c) the attachment into the extensor pollicis longus tendon

The IP joint is transfixed with a K wire to ensure that the thumb is immobilised in an optimal position. The hand is thereafter immobilised in a cast.

Postoperative treatment

The cast and the K wire are removed after four weeks. The patient is fitted with a small plastic splint (Orfit ©) that supports the IP joint in 20° of flexion but leaves part of the pulp free for contact with the index finger during gripping (Figure 7). After six to eight weeks the patient is free to use the hand without the splint. However, all personal transfers are not allowed until three months postoperatively (104).

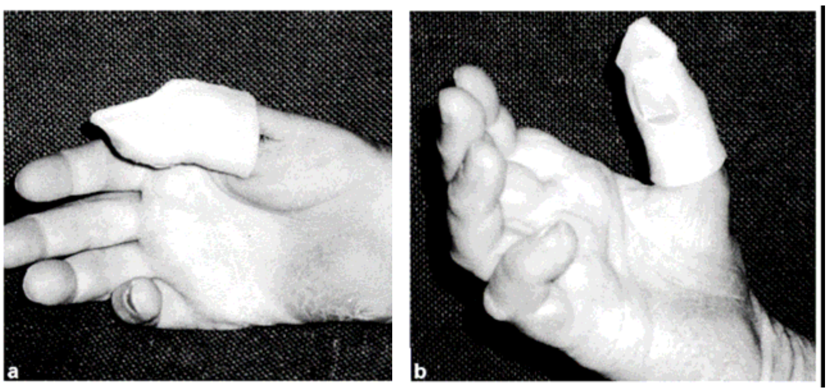

Figure 7. The thumb splint, (a) Radial view, (b) Volar view, showing the free part of the pulp of the thumb.

Study III

Patient population

This study was a cross-sectional study and data were collected between 1994 and 2003. The group consisted of 55 patients, 52 patients with traumatic SCI and three patients with acute vascular injury. To discern the motor level and sensory level of the patients, the MMT and 2PD were translated according to the American Spinal Injury Association (ASIA) (4). The ASIA motor levels showed that 33 patients (60%) had the same motor level in both arms and those 20 patients (36%) showed an asymmetric pattern. Two patients (2%) were not included owing to a lack of data in the MMT test. Dermatomes C6, C7 and C8 were used only during sensory testing; it is therefore not possible to give an accurate ASIA grading of injury (Figure 8). The hand surgeons were responsible for the MMT test and the 2PD test. A specialist in neurology classified the patients according to the ASIA motor level and ASIA sensory level. The data were derived from the MMT test and the 2PD test.

Right hand \ Left hand	C4	C5	C6	C7	C8	>C8	NT
C4	0	1	0	0	0	0	0
C5	0	5	6	0	0	0	0
C6	1	3	13	2	0	0	0
C7	1	1	0	12	2	0	1
C8	0	0	0	1	2	1	0
>C8	0	0	0	0	0	1	0
NT	0	0	0	0	0	0	0

Figure 8. ASIA motor level divided into right and left hand (n=53)

Measurement - K-B ADL Scale

The Klein-Bell ADL Scale (K-B Scale) (105, 106) is a generic instrument and has been translated into Swedish (107) and has in previous studies demonstrated reliability (106, 108, 109) and validity (106, 109) as well as sensitivity toward small changes in ADL (108, 110). The K-B Scale (105, 106) operationalise the concept of functional independence in terms of a patient's level of independence into six dimensions: dressing, elimination, mobility, bathing and hygiene, eating and emergency telephone use. The K-B Scale (105, 106) can be applied in persons with or without disability and is constructed to measure basic ADL in detail. The activities are divided into essential components (items) and each component is scored separately. The scale can be used to assess basic ADL with a raw

sum score or with a weight score in 170 items (105, 106).The majority of items (162 items) measure activities of daily living (dressing, bladder and bowel management, mobility, hygiene, eating and drinking and using the telephone) while eight items measure body function (bladder and bowel emptying, bladder and bowel incontinence, chewing and swallowing food, swallowing liquids, verbalizing telephone messages). Under the assumption that some items are more difficult, time consuming etc. than others for all people a weight scheme (105, 106) was developed. Each item in the original K-B Scale was rated in an empirical manner by rehabilitation professionals on a five-point scale with four criteria: “1. How difficult is it for average able-bodied persons? 2. How difficult is it for the average able-bodied person to perform this activity for someone else (to provide maximum assistance)? 3. How much time does it take to perform this activity? 4. How injurious to one’s health would it be if the activity could not be performed?” (106) (page 336). A mean rating was obtain for each rater, the frequency distribution was calculated for each item and the items were then given a weight score from 1 to 3, where weight 3 is given to the most complex items (105, 106). Weights 1, 2 and 3 from the original construction are used in the analysis. The weights will be referred to as simple, average complex and complex, respectively (105). Eleven items in the K-B Scale lack an individual weight score in the weight scheme (105). For this reason only 159 items were included in the analysis of the weight scheme. The 159 items in the weight scheme are divided into 29 simple items, 108 average complex items and 22 complex items (105, 106).
In the present study the assessment of a patient’s level of independence in basic ADL was made via a semi-structured interview conducted by the first author. The K-B Scale was presented verbally to the patient prior to the interview and the interview time ranged between 35 and 45 minutes. All interviews were conducted at the SCI Unit. The patients in this study were asked what they in fact do or carry out on a regular basis to assess the actual activity level in the person’s real life surroundings. Diagnosis-specific questions were used to verify uncertain answers during the interview and to include more information, such as on the use of assistive devices and car and house adaptations. The dichotomized categories of independent with or without assistive devices (3 points) and dependent with verbal or physical assistance (0 points) (105, 106) in each item were used to analyse the patients’ independence. Gender-specific items for the opposite gender and diagnose-specific items were registered as not applicable items.
A data program called the ADL diagram © (111) was developed to compile the raw sum score to recommendations in the K-B Scale manual (105, 106, 112). The analyses made with the ADL diagram © show each item per patient and raw sum score in 170 items. A patient who carries out an item independently receives a raw score of three points; if he/she is unable to carry out the item, a raw score of zero points is given. The raw sum sum score ranges from 0 (dependence) to 510 points (independence) in the K-B Scale (112).

Linking K-B ADL Scale to the ICF

To better understand the relationship between function and activity performance (113) the items in the K-B Scale were linked (44) in the present study to the ICF. The linkage process (44) (paper III) between the K-B Scale and the ICF (40) was first to investigate which health domains the scale covered and second to examine whether arm and grip function could be detected in the items' operational criteria using Napier's (114) definition of precision and power grips together with Bendz's (115) description of grip ability from the opening phase to the terminal opening phase in the grip procedure. The linkage was made by one health professional (AD) on the basis of the ten linking rules (44) developed to link the health status instrument to the ICF. The linkage process was conducted in Swedish. An individual perspective and activities (i.e. tasks or actions that an individual does) was used during the linkage process. The concept of activity in the ICF (40) is defined as the execution of a task or action by an individual (116). It can refer to either an individual's capacity to carry out a task or to that person's actual performance of the task. During the linkage process the K-B Scale was linked to the ICF components (40) of body function (bladder and bowel function), activities and participation (arm and hand function and self-care) and environmental factors (assistive devices). If more than one code is used per item definition, the codes appear marked in italics in sequence in the text. If the content of an item is not explicitly named in the corresponding ICF category, then "other specified" option was linked at the third and the fourth coding levels of the ICF classification. When ICF categories were too general, the additional information in the item definitions was coded to keep the level of detail of the K-B Scale intact (44).

Statistical analysis

Study I

The data in study I, elongation in tendon transfer and range of motion (ROM) in elbow extension, were compared and tested for differences across groups (117). The data were compared statistically with one-way ANOVA between patients who received and did not receive the armrest support. Elbow extension was reported as elbow extension deficit with mean and SD. The Independent T-test was used to compare the groups concerning elbow extension deficit. A two-way ANOVA was used to test for interaction between post-operative time periods and the effect of the armrest (117). A significance level (α) of .05 was chosen and the statistical power (1-β) was calculated as 71% using the equation of Sokol and Rohlf (118).

Study II

The mean and standard deviation (SD) of the data in study II were used to describe whether the postoperative treatment with thumb splint influenced the long-term effects on active and passive ROM in the thumb's IP joint. An additional description was presented for the data at the six-month follow-up due to a high number of missing data (n=15) at the 12-month follow-up. It included mean value and standard deviation (SD) to describe whether the data in the group that lacked data differed from the group that had data at the 12-month follow-up. A missing data analysis was made to investigate whether a difference in extension, flexion and ROM existed at the six-month follow-up. The groups; group 1 (missing data at the 12-month follow-up) and group 2 (had data at the 12-month follow-up) were compared using an independent T-test and 95% confidence intervals (CI) for mean differences (20).

Study III

The data in study III were tested to investigate whether a difference in complexity existed between the original weight levels in the K-B Scale (105, 106). The original weight levels in the K-B Scale (simple, average complex, complex) were compared with a paired T-test and 95% confidence intervals (CI) for the mean differences (20).

The raw sum score in the K-B Scale (105, 106) and the upper extremity motor score (UEMS) in both arms were tested to measure whether a relationship existed between independence in ADL and upper extremities function. The same test was carried out between the raw sum score in the K-B Scale and the sensory function in number of fingers with ≤ 10 mm in the 2PD test. The data in this study were analysed with Spearman's rank correlation test to detect whether a relationship existed between the K-B Scale raw sum score and UEMS. The same test was done between K-B Scale raw sum score and the 2PD test.

Three further analyses were made and the results of these three analyses are given in descriptive statistics; the first analysis examined whether assistive devices influenced the patient's independence. The second and the third analyses investigated whether arm and grip function could be detected in the items' operational criteria in the K-B Scale.

RESULTS

Study I - Protection of the deltoid to triceps tendon transfer repair sites

The tendon elongation measurements made six months after surgery showed a total distance between metal markers in the patients with manual wheelchair and without armrests of 23.1 ± 4.8 mm. The corresponding values for the patients with electric power wheelchair and special armrests was significantly lower 8.4 ± 3.0 mm ($p < .05$). All the elongations in the armrest group occurred within six weeks. Only 60% of the elongation occurred within the first six weeks in the nonrestricted group. There was no significant difference between the groups for any metal marker intervals four to six weeks after surgery ($p > .4$). The greater part of the elongation in both groups occurred in the proximal interval. The elongation in the distal attachments was essentially the same for both groups; 4.0 ± 4.0 mm in the armrest group and 3.2 ± 3.2 mm in the nonrestricted group (p

> .8). Three of six patients in the nonrestricted group had an elbow extension deficit of more than 20°. In the restricted group, only one patient, who was not able to comply with the postoperative regimen, had an elbow extension deficit. The elbow extension deficit was decreased, but not significantly, when compared with the extension deficit measured before the use of the armrest, 7° ± 2° vs 15° ± 5° ($p = > .1$).

Study II - Split distal flexor pollicis longus tenodesis: long-term results

The mean (SD) active ROM in the IP joint six and 12 months after the operation was 28° (18°) (n=37) and 23° (20°) (n=25) respectively. Six months after the operation, the mean (SD) active extension was -4° (18°) and mean active flexion 32° (14°). One year post-operatively, 20 of 22 hands had an active flexion in the IP joint ranging from 15°-60°. Six months postoperatively, the passive IP joint flexion exceeded active flexion by about 23° in 22 hands.

In the missing data analysis, the mean (SD) in group 1 (missing data at the 12-month follow-up) and group 2 (had data at the 12-month follow-up) was reported for extension, flexion and ROM of the IP joint (Table 2).

Table 2. Missing data analysis with extension, flexion and range of motion in the IP joint 6 months post-operatively. Data are mean (SD)°.

6 months	Group 1 (n=15)	Group 2 (n=22)
Extension	-2 (18)°	-6 (18)°
Flexion	26 (12)°	36 (14)°
Range of motion	25 (13)°	29 (22)°

The comparison between the different movements (extension, flexion, ROM) showed a statistically significant difference in degree of movement between flexion in group 1 as compared to group 2 (Table 3). This difference was nine percentage units. The comparison between extension and ROM in the groups showed no statistically significant difference; the difference was 4.7 percentage units in both groups (Table 3). Clinically, group 1 had more extension and less flexion and ROM in the IP joint of the thumb compared to group 2.

Table 3. Independent sample T-test for every value of movement in group 1 and group 2 divided by extension, flexion, ROM

Movement	Mean percent-age units	95% Confidence Interval of the Difference		P-value
		Lower	Upper	
Extension 1 – Extension 2	4,697	7,776	17,170	,448
Flexion 1 – Flexion 2	-9,348	-18,297	-0,400	,041
ROM 1 – ROM 2	-4,652	-16,395	7,092	0.43

The median values in extension in groups 1 and 2 are 0° and -7,5°, respectively, in flexion 30° and 37.5°, respectively, and in ROM 25° and 27.5° respectively. These are visualised in figure 9.

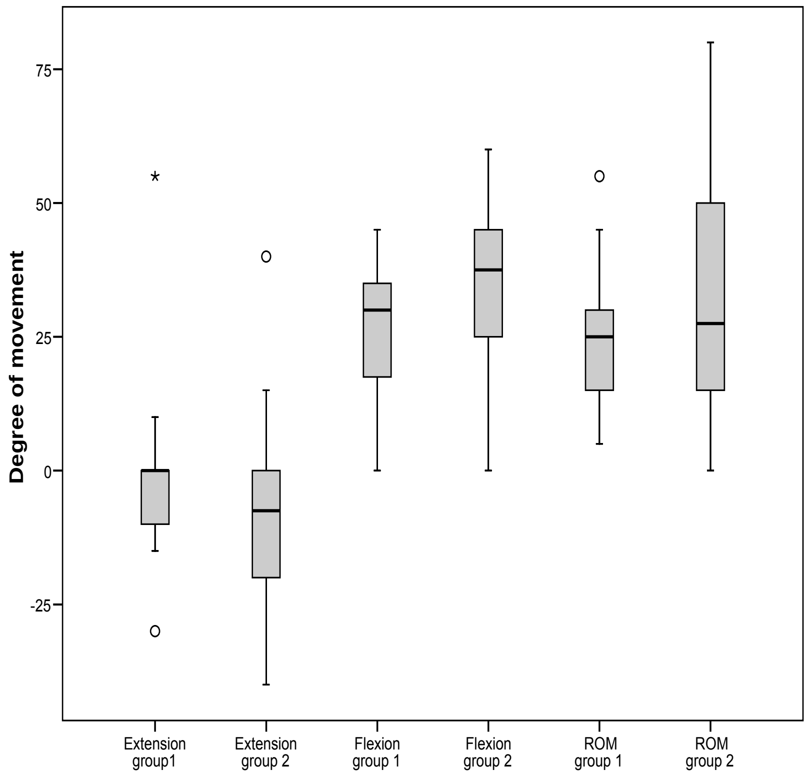

Figure 9. Boxplot for extension, flexion and ROM divided into group 1 (n=15) and group 2 (n=22)

Study III - Discrimination and applicability of the K-B ADL Scale

The K-B Scale is applicable for assessments of basic ADL in cervical SCI patients and can discriminate patients with a low ability to a high ability for carrying out basic ADL (Figure 2). The majority of items (162 items) measure activities of daily living (dressing, bladder and bowel management, mobility, hygiene, eating and drinking and using the telephone) while eight items measure body function (bladder and bowel emptying, bladder and bowel incontinence, chewing and swallowing food, swallowing liquids, verbalizing telephone messages). The raw sum score in the patients in the K-B Scale ranged from 42 to 456 points. Thirty-two of 55 patients had less than 50 % of the raw sum score.

One hundred and fifty-nine items in the dimensions (emergency telephone use, eating, mobility, hygiene and bathing, dressing and elimination) according to the K-B Scale are ordered with respect to the proportion of independent patients in the dimension of use of telephone to the dimension of elimination. Most of the patients were independent in the dimensions of use of telephone and eating. Nineteen patients (34%) in the study group (n= 5 ambulatory with or without assistive device and n=14 used wheelchair) were more independent in transfers and overall independence than the rest of the group.
The patients in the whole group were most dependent in the dimensions of elimination, which includes bladder and bowel management. Using assistive devices and car and house adaptations makes the patients more independent in ADL (¤ = assistive devices and # = house and car adaptations). Assistive devices can either be applied to the hand or be handled with active grip function. The patients were more dependent in items including grip function visualised through linking the K-B Scale to the ICF and analyses with Napier's and Bendz's definition of grip function. This is most clearly seen in dressing the lower body (marked by dark grey squares = arm/hand function). In the majority of items where precision grip is a prerequisite the patients are more dependent in parts of dimensions. This is most clearly seen in the dimension of dressing in the case of putting on shoes, trousers, shirt, jacket and bra and in cutting nails (marked by light grey squares = precision grips) (Figure 10). Assistive devices were used in 68% of the items and car and house adaptations were used in 11% of the items. Eighty-two percent of the 159 items required grip function and 22% of these items required precision grip. Assistive devices compensate for the loss of grip function in 57% of 159 items (Figure 10).

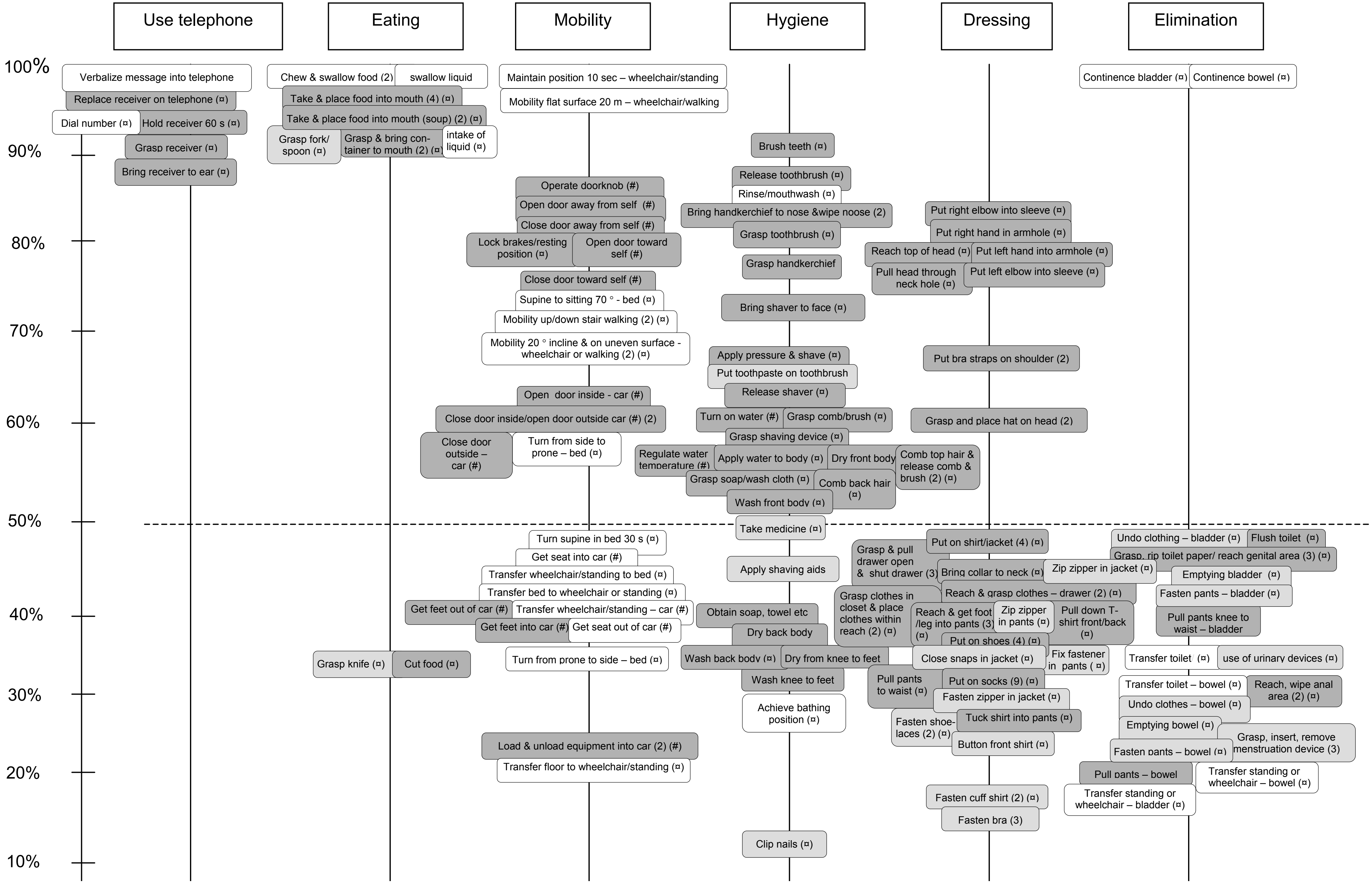

Figure 10. The proportion of independent patients in 159 items divided into the dimensions of use of telephone, eating, mobility, hygiene, dressing and elimination in the Klein-Bell ADL Scale. (n=55) ( ) = number of items included in parentheses, (¤) = assistive devices, (#) = house and car adaptations, marked dark grey squares = arm function and hand function, i.e. grasp abilities needed to perform the item(s), marked by light grey squares = precision grips, i.e. manipulation needed to perform the item(s).

Correlation between the K-B Scale and upper extremity function

The patients' raw sum scores ranged from 42 to 456 in the K-B Scale and from 23 to 184 in the UEMS. There was a moderate correlation between the raw sum score in the K-B Scale and the UEMS including muscles from the shoulder to the intrinsics, $r_s = 0.63$ (P<0,01). The patients' sensibility ranged from no sensory function in all fingers to full sensory function in all fingers according to the 2PD test divided into ASIA sensory level. There was a moderate correlation between the raw sum score in the K-B Scale and the 2PD test with ≤ 10 mm in number of fingers, $r_s = 0.68$ (P<0.01).

Analysis of the weight scheme in the K-B Scale

The proportion of patients that carried out the item independently was calculated for each item. These proportions were grouped according to the K-B weight scheme: simple, average complex and complex. Simple items (25^{th}-75^{th} percentiles) ranged between 46% and 83% (median of 60%), average complex items between 35% and 77% (median of 44%) and complex items between 27% and 79% (median of 53%) (Figure 11).

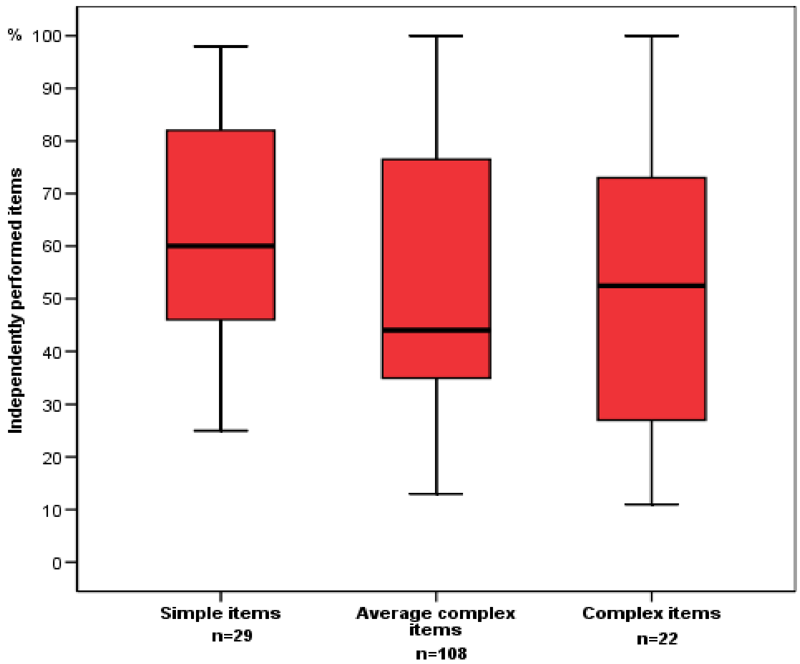

Figure 11. The proportion of patients that independently performed items classified as simple, average complex and complex items in the Klein-Bell ADL Scale.

The proportions of items in the K-B Scale performed independently by the patients were calculated for each of the three weight levels. The mean percentage groups were 64% in the simple items, 55% in the average complex items and 61% in the complex items. The proportions were thereafter tested with regard to differences between the weight levels in the K-B Scale. The comparison between the weight levels showed that there was a difference in complexity between simple items and average complex items. This difference was 8.5 percentage units, and there was an inverted difference in complexity between average complex items and complex items of 5.6 percentage units. Both comparisons between the weight levels were significant, $P<0.000$ and $P<0.002$, respectively. The comparison between simple items and complex items showed no statistically significant difference ($P<0.158$). The difference was 2.9 percentage units.

Investigate grip function - linking the K-B Scale to the ICF

Linking the K-B Scale to the ICF together with Napier's definition and Bendz's description of grip function, has showed that the need for arm and hand function, i.e. grasp ability, exists in all three levels in the K-B Scale's weight scheme. The items included either precision grips or power grips or a combination of the two. Simple items include those that either prepare or terminate an activity. Both average complex items and complex items involve performing or continuing an activity with static or dynamic grasp patterns. Precision grip (manipulation), a dynamic grasp ability were more common in average complex items.

Analyses of the structural properties in the K-B Scale

The analysis of the structural properties in the K-B Scale showed problems in 46 of 170 items during the measurement process. The distribution of these items was as follows: 34 items did not make any differences in functional limitations, i.e. the items included different assessment alternatives owing to the formulation of the items' operational criteria. The majority of the 34 items were found in the dimensions of elimination and mobility. The assessment alternatives ranged between being independent in ADL without assistive devices and being independent with assistive devices. Seven items that included assessment of extra devices were not relevant for cervical SCI patients. Five functional items (bladder and bowel incontinence, chewing and swallowing food and swallowing liquids) showed a ceiling effect, i.e. all patients were assessed as independent.

DISCUSSION

The main findings of these studies are threefold:
1. The postoperative treatment with electric power driven wheelchair and special armrest after reconstruction of elbow extension reduces tendon elongation by approximately 36% compared with a postoperative treatment not using an armrest.

2. The postoperative treatment with a splint after split distal thumb tenodesis protects the surgery over time, and the active range of motion is almost 30° in the IP joint one year after the operation.

3. The K-B Scale can discriminate cervical SCI patients' ability to carry out basic ADL from lesser to greater independence in ADL. Only the analysis with the raw sum score was useful in cervical SCI patients.

Research on clinical practice is important to generate knowledge, findings and evidence about measurements, interventions and outcomes of therapy (119). The evaluation of the utility of new treatment tools in study I and new treatment processes after surgery in study II have demonstrated an improvement in arm and hand function in cervical SCI patients (120, 121). The examination of the K-B ADL Scale quality of measurement carried out in study III showed that the cervical SCI patients ability can be discriminated with regard to level of independence (122).

Outcome measures

It is crucial that functional gains after a surgical intervention also have an impact or meaning in clinical or in real life (119). Study I, which investigated special armrest together with electric power driven wheelchair, and study II, which examined split FPL tenodesis, both showed a positive influence on the patient's function after surgery. The patients actively extended the elbows better when electric power driven wheelchair and special armrest was used as compared with the non-restricted group. With the split FPL tenodesis in study II the patients had a stabilised IP joint and yet a pliable joint. The range of movement, even though it is small compared to normal ROM, makes the thumb grip (key grip) easier to use in daily activities. Connecting basic movement in the upper extremities to basic ADL (study III) might give an understanding of the arm and grasp abilities needed to perform an activity (122). To capture these functional gains and real-life benefit after an intervention it is thus important in clinical research to select appropriate outcome measures on all levels, from body function and structure to activity and participation (40).

The knowledge gained and evidence of interventions and measurements have shown that electric power driven wheelchair and special armrest and FPL tenodesis are suitable solutions for tetraplegic patients to gain full active elbow extension and well balanced thumb flexion. Although the overall time for rehabilitation after reconstruction of elbow extension can be long, the functional gain is substantial, predictable and easily appreciated by the patient. However, even though the combination of armrest and electric power driven wheelchair has a positive impact on the surgical results, it has been suggested (123) that the lengthy period of immobilisation is too cumbersome because it restricts the patient's ability to be mobile and active in daily life. Factors such as preoperative function in the ROM in the IP joint in the thumb as well as thumb flexion and time between procedures must be considered to gain optimal results of surgery. If there is a strong thumb flexor without a strong antagonist in the thumb extensor or the time between interventions is less than four to six months, the tenodesis should be carefully protected to eliminate the possibility of overloading it during functional training and in daily activities (121).

Clinical implication

The results confirm our clinical experience that both the interventions in the study I reconstruction of elbow extension and the study II tenodesis of the IP joint of the thumb needed to be protected for different time periods after surgery and that the K-B Scale can measure ADL ability in cervical SCI patients. The special armrest prevented shoulder adduction and the use of an electric power driven wheelchair prevented forward stretch of the arm (72, 120). However, even with electric power driven wheelchair and special armrest, the proximal portion of the graft-tendon unit elongates, more pronouncedly than in the distal portion. This elongation takes place early after surgery and may have a negative influence on the functional outcome. The elongation in the distal portion of graft tendon unit was comparable in the two postoperative protocols (72). Patients with cervical SCI often learn compensatory movements and techniques that help them to interact with objects. However, despite these adaptations, the grasp functions usually remain considerably restricted and further improvement may be required (124). Reconstruction of active thumb flexion with an absence of active thenar muscle control will lead to full active flexion in the IP joint. The surface area is reduced since the tip, and not the pulp, of the thumb is applied to the radial side of the index finger (121). However, the thumb splint protected the IP joint from excessive movement and, postoperatively, the IP joint remained at almost 30° in ROM, which is considered ((125) to be the ideal motion for this type of procedure. The orthosis with volar opening also enables the patient to use the sensation in the thumb pulp during the retraining process and during grip training in daily activities. Furthermore, the new operative procedure has solved a great problem and eliminated the need for temporary or permanent arthrodesis of the IP joint in severely paralysed hands (121).

Cervical SCI patients often make small but significant functional gains, to a greater extent within an activity than in an entire activity (126). Study III showed that the K-B Scale, compared to the Spinal Cord Independence Measure (SCIM) (127) and Quadraplegia index of function (QIF), (126) can measure ADL in finer detail since items in the SCIM and the QIF lack the necessary components to assess important parts of an activity. The K-B Scale is able to make this distinction, and the scale is therefore more sensitive to detecting problematic activities in ADL in cervical SCI patients. These attributes can make the K-B Scale a better tool for targeting interventions in ADL for cervical SCI patients (122).

Retrospective and cross-sectional designs

Using existing data to pose and answer a research question may seem less demanding than asking a question and then collecting the data to answer it. The researcher does not have direct control of the variable under study because it has occurred in the past or represents attribute variables that cannot be manipulated (128). Study I and study II are both retrospective studies and derived from an interest in developing and expanding clinical knowledge that could directly contribute to improving the functional outcome after surgery. Study I evaluated the improvement emanating from the irritation in the clinical setting over the long term results demonstrating an elongation of the tendon transfers that influenced the functional outcome after surgery. Study II investigated whether the functional outcome in IP joint motions of the thumb could be influenced over time after the introduction of a new surgical procedure. When using secondary data, it is important to evaluate the data and weigh potential biases to minimize the potential pitfalls of retrospective studies (119). The findings in study I and study II have shown promising results and could provide the basis for further investigation and research using a prospective research design to gain better control over data collection methods (128).

The major advantage of a cross-sectional design is that it is relatively easy to conduct, does not take a long time to execute and is less expensive than other research designs (119). Moreover, a cross-sectional study gives a snapshot of a single sample measured at one time point, for example to examine the extent to which health behaviour or conditions exist in a group (128). Study III is a cross-sectional study derived from an interest in finding and evaluating an ADL scale for its measurement qualities and for its ability to measure changes in basic ADL in connection with reconstructive arm and hand surgery. The limitations of this type of study are that it cannot distinguish the temporal sequence of cause and effect, and it only gives a snapshot of a person’s status at a given point in time, which might falsely classify a person as being more dependent or independent in ADL. A third limitation in study III is that, although it is a cross-sectional study, the data were collected over several years and the care and rehabilitation the patients received might have changed over time. This might have influenced the results of study III.

Power analysis

The power of a test is the likelihood that it will detect a difference when one exists. The desired power or recommended level of power is .80 or 80%. Large between-group differences, small within group differences and large sample sizes are needed for the power of a test to have high power (129). However, when very small samples are used, as is often seen in clinical research, the power is reduced. This is the case in study I, where the power is below the recommended level. Even though the power is low, however, the results indicated a significant difference in tendon elongation and functional outcome between the two groups, which is clinically useful. Study I should thus perhaps be seen more as an exploratory study to determine whether the new treatment influenced the postoperative results rather than to provide definite evidence for the approach. A next step might therefore be to carry out a new study with a more powerful design to investigate the effects of using the special armrest after reconstruction of elbow extension (129).

Missing data analysis

Almost all studies have some missing data and this can occur at the subject and/or item level. Missing data at the subject level are usually found in longitudinal and repeated measures studies when one or more persons are lost to follow-up or decide not to continue their participation in the study. Study II, concerning tenodesis of the IP joint, lacked data in 15 out of 37 hands (40%) at the follow-up 12 months after the intervention. When data are missing, there is a need to identify the pattern or amount of missing data to assess why they are missing and determine what to do about it (117). The missing data in study II can be explained by two major factors: no measurements were made at follow-ups due to a lack of a standard protocol or a patient who had good or very poor results of surgery did not attend the follow-up. Flexor tendon healing occurs within three months after surgery (85, 86) and, since patients are allowed to use their hand in daily activities early during postoperative treatment, a more dynamic healing occurs over time (87, 88). It was therefore assumed that the data at the six-month follow-up would show whether any elongation occurred in the tenodesis that influenced extension, flexion and ROM in the whole group. The data in study II at the six-month follow-up were therefore split into two groups and used in the missing data analysis. While the statistical analysis showed no differences in extension and ROM between the groups, a small but statistically significant difference was shown for flexion between the groups. Group 1 had a smaller flexion motion in the IP joint of the thumb than group 2. Clinically, the contact area between the thumb and index finger would have been greater, and this could influence the patient's ability to grasp in ADL. This analysis can therefore strengthen previous results (121) that tenodesis of the IP joint intervention has solved a great problem in reconstruction of the thumb grip in severely paralysed hands.

Measurement of body function and activity level

Study III made no distinction between complete and incomplete patients compared to other studies that included only motor complete cervical SCI patients (130, 131). This might explain the moderate correlation in study III between motor and sensory function in the upper extremities and the patient's level of independence in ADL (122). Another explanation might be that measurements of body function level do not allow a direct translation to the activity level: hence the moderate correlation in study III because measurements of body function level are based on capacity and not on performance as the ADL is (132). Clinically this means that there might be a discrepancy between the patients level of function compared to what the patient actually does in daily life.

Marino et al. (130) reported that motor level is superior to neurological level in determining the relationship with functional tasks. They further stated that, while motor level is a better predictor of self-care than neurological level, key muscles at different motor levels may not be responsible for the improved ability in ADL. However, other studies (6, 47, 131) have reported that a specific relationship exists between critical levels or key muscle groups and independence in certain ADL activities. Earlier studies (133, 134) have suggested that differences in ADL abilities among cervical SCI persons with a similar motor level could be attributed to differences in sensory function. Analysing by level, whether neurological or motor, can render important information for predicting outcome, but does not necessarily identify the relative contribution of muscle groups to the completion of various tasks. These variations in results suggest that task performance is not just a function of muscle strength or sensory ability but also of skill, motivation and the patient's physical characteristics (131).

Independence and functional mobility

Functional mobility (transfers and wheelchair propulsion) in individuals with tetraplegia represents a significant factor in overall independence in ADL (135). In study III a small sample showed the same combination between being able to make transfers and overall independence. One of the greatest barriers to independence is the inability to support and lift the upper body using the upper limbs (i.e. performing a weight-relief manoeuvre) (52). A number of studies have reported that upper extremity function and movement, that is, in transfer and push-up motions, is decisive in the process of gaining and maintaining independence (47, 52, 53, 131). Without these skills, individuals are not able to transfer, which influences their independence in other tasks necessary for mobility and self-care (52). The more independent patients in study III could make bed transfers by themselves, which also made them independent in getting clothes and dressing the lower body. However, the patients' physical characteristics, such as height and weight, were not taken into account, which might have further explained why these patients were more independent than the rest of the study group.

Functional mobility and measurement

The results of study III highlight inherent problems in the mobility domain in the K-B Scale because assistive devices are included in the item definitions. For this reason the items are not sensitive to change in function; neither do the items distinguish between individuals with different levels of injury. Despite the existence of these problems, a degree of skill difficulty could be discerned between the different transfer modalities, and this was corroborated by other studies (131, 136). The patients in study III were most dependent in negotiating stairs, followed by transfer from floor to wheelchair, and thereafter transfer to toilet, shower chair and bed.

In comparing the mobility domain in the K-B Scale with the Functional Independence Measure (FIM™) (137) the K-B scale can measure different modalities of mobility in greater detail than the FIM™, even though a recent study (136) has suggested that five additional mobility items (move about in bed, transfer floor to wheelchair, push a manual wheelchair over level ground, ramps and kerbs) be included in the FIM™.. These items were included in the FIM™ to capture important factors influencing mobility and to distinguish important functional differences among the SCI population. However, the item definition of these five items suggests testing in a standardised environment, and the assessment seems to be based on capability not performance. However, capability (can do) is a very different phenomenon than actual performance (does do). Measures of capability establish the limits of performance but are generally poor indicators of actual behaviour. A crucial distinction between measures of capability and of actual functioning is where the behaviour occurs. Clinically, getting up from a supine position on a gymnastic plinth (hard surface) does not necessarily mean that the patient can do the same procedure in a bed on a soft mattress (soft surface). Actual performance can, compared to capability, only be measured in places where persons conduct day-to-day living (138). Furthermore, a person's performance of an activity is a result of the integral interaction between the person, the activity and the environment (139). In study III the patient's actual performance was therefore assessed in the K-B Scale in an attempt to capture what the patients did on a regular basis in their real life surroundings.

Assessment of ADL - hierarchy and dimension

It has been proposed that ADL activities can have different level of skill difficulty, i.e. that they be divided into easier and more difficult activities, as some ADL activities require skills and physical ability to balance and maintain a stable position either standing or sitting while using the arms and hands (140). The results of study III confirm previous findings that patients' highest levels of independence are attained in easier self-care activities (7, 45, 49, 51). The patient's level of independence appears to be related to skill difficulty. Eating and using the telephone were the easiest activities, while grooming, dressing upper body intermediate, transfers, showering, dressing lower body, and bladder and bowel management required greater motor ability to achieve proficiency. This suggests a hierarchy among ADL activities and assumes that each activity reflects a certain level of difficulty (141). Hierarchy, however also implies that activities are combined in such a way that they provide information about activities or items ranging from a less to a more common ability representing one underlying dimension called dimensionality (141). When a scale is unidimensional, it contains items that intercorrelate; the items should span the entire range of patient functional independence, and the difficulty of each item should be consistent for all patients (142). Using this approach in an ADL assessment, in addition to being efficient, has the potential of achieving precision by focusing on more detailed questions at the ability level of the person (119).

Assessment of ADL - multidimensionality

ADL has been suggested to be multidimensional and divided into self-care, sphincter control and mobility, which is relevant to most individuals at all levels of physical disability (140, 143). In study III these dimensions were identified in the K-B Scale through the process of linking to the ICF (122). As these dimensions have been shown to influence independence among cervical SCI patients in both previous studies (61, 131, 136) and in study III, all three dimensions should be included in the investigation of independence in cervical SCI patients. However, as these dimensions measure self-care, physiological function and the ability to be mobile (40) and are therefore distinctly different from each other, they should preferably be investigated as separate dimensions. Being able to delineate these domains allows gaining a more complete picture of a patient's ADL ability. Clinically, either domain or all domains could show change as a result of an intervention. Furthermore, differences in progress among the dimensions at various stages during rehabilitation can be highlighted.

Impairment-specific dimensions

Impairment-specific dimensions have been suggested in earlier studies (143, 144) to be identified and measurable in ADL scales. In study III a connection between function and activity was established by using Napier's definition (114) and Bendz's description of grip function (115) during the linking of the K-B Scale to the ICF. The K-B Scale can compared to FIM™ not only be divided into upper and lower body but also be divided into impairment-specific items for arm and hand function. In its present form, however, the K-B Scale can not differentiate the quality or types of grip function needed to perform ADL. To measure this, evaluation tests of body functions and structure and dexterity level must be included, preferably on level of performance not based on capacity (132).

Linking the K-B Scale to the ICF

The ICF (40) is recommended to be used as the basis for interpreting an individual's overall function. The classification proved useful in study III for content comparison in parts of the K-B Scale. Arm and hand function could be elucidated and was strengthened on the item level through the linking process (44). Mobility items could be linked with high precision to the ICF. It showed that many items were related to mobility, arm and hand function. Some items required large physical movement components (trunk balance), elbow extension and grip function (putting on socks and shoes, dressing lower body, transfer from floor to wheelchair, load and unload wheelchair into car, insert suppository before emptying bowel, showering etc.). The content of the K-B Scale concerning ADL differed with regard to which categories were covered within the component Activities and Participation. Several recoding procedures had to be performed to keep the level of detail in the K-B Scale intact when linking the self-care categories in the scale to the ICF. The categories in self-care in the ICF lacked both breadth and depth in their category definitions. Even though parts of the linkage process were problematic, the linkage made it possible to study similarities and differences between the K-B Scale and the ICF in body functions, activities and participation, and environmental factors. A limitation in the linking process was that one person (AD) did the linkage between the K-B Scale and the ICF, whereas it is suggested in the linkage rules (44) that two persons should be part of the procedure. However, linking measures to the ICF could bridge the gap between function and activity as the relationship between measures of disability and impairment is not clear (43, 145).

Analyses of the structural properties in the K-B Scale

Quality of measurement includes not only the quality of the measurement instruments but also the quality of the performance of the actual measurements (146). The K-B Scale is constructed to measure basic ADL in detail (105, 106) and the structural properties of the K-B Scale have been investigated previously, including both reliability and validity (106, 108, 109) as well as sensitivity toward small changes in ADL (108, 110). However, in earlier studies concerning ADL, the SCI patient's levels of injury either remain unclear (106) or include few cervical SCI patients (147). It was therefore important in study III to examine the measurement properties of the K-B Scale to ascertain whether the scale can discriminate cervical SCI patients at baseline before evaluating the patients' basic ADL in connection with reconstructive arm and hand surgery. If the patients cannot be discriminated at baseline, then how can the same instrument evaluate their subsequent course of change in basic ADL? An evaluative instrument that has a clear discriminative function could help the clinician to decide whether a patient is changing relative to his or her own baseline (148). Furthermore, the quality of performance of the K-B Scale depends for example on the person carrying out the interviews and the group of patients and their interest in answering the questionnaire (146).

Generic vis a vis diagnosis-specific instruments

Generic instruments would provide an opportunity to compare patients across disorders, diseases and interventions compared to a diagnose-specific instrument (149). However, even though the results of study III show that the K-B Scale can tap into many important areas of ADL for cervical SCI patients and discriminate them according to ADL function, it has all the inherent problems associated with a generic scale. The K-B Scale includes items that are both inappropriate and irrelevant for cervical SCI, and these non-useful items contribute only noise when the instrument is used and subsequently analysed.

The use of semi-structured interviews

The total number of items in a scale is generally related to precision, i.e. how well a scale can discriminate for example ADL ability among cervical SCI patients (119). However, the total number of items also affects how much time is needed for the measurement (150). In study III a semi-structured interview was chosen even though the K-B scale includes many items. The interviewer is allowed to tailor questions and probes to obtain in-depth and trustworthy information. This includes questions concerning what, how, why, where and when certain activities are performed (35). These questions give a more thorough understanding of ADL ability, not only that which depends on the patient’s abilities and skills but also about task requirements and environmental factors. However, there must be a balance between how much information is needed and how long an interview can be in order not to burden the patients too much. The limitation in using a semi-structured interview is that there is always a risk of interview bias (119).

One way to lessen the burden to the respondent would be to develop a computerized adaptive test (CAT) as it eliminates the need to use all the items in an instrument to derive a measure. When a CAT is used the assessment begins with key questions that focus on the patient’s levels of ability to perform ADL. These questions will place patients with different ADL abilities along a continuum from easy to difficult item. Selective items will thereafter be administered depending on the answers in items previously administered until a measure has been derived of the patient’s level of ADL ability. It has been suggested that a CAT-based assessment can be administered without losing the accuracy of full tests or whole instruments. This will decrease the time needed to make the assessment and reduce costs while managing the ADL scale both clinically and for research (119)

Categories in the K-B Scale

It has been suggested that the minimum number of categories in a scale should be between five and seven (149). Regardless of how many categories are incorporated in a scale, all should be applicable and measurable in all items (151). If the numbers of categories is less than the rater's ability to discriminate, the result will be loss of information (149). This is clearly seen in study III, where the use of dichotomized categories, independence and dependence in the KB Scale limit the patients' choice of response levels, which in turn leads to a loss of efficiency in discriminating patients' level of independence. Furthermore, the use of dichotomized categories also reduces the correlation with other instruments or measures (149).

One of many improvements after reconstructive surgery was that patients either discarded assistive devices or began to use assistive devices that allowed them to be independent without the help of others (38). Clinically these changes in activity pattern are important to the patients, and it should be possible to measure the utilization of assistive devices in the K-B Scale. The Swedish version of the K-B Scale (107) includes a category to measure the use of assistive devices apart from categories that measure independence, partly dependence and totally dependence. As the number of categories in a scale defines the sensitivity to change in patient ADL ability in an item (150), all these categories should be used in future assessments and evaluations to better discriminate the patient's independence in ADL.

Weight scheme in the K-B Scale

Earlier studies (49, 152, 153) and study III show that patients who have greater motor ability tend to be more independent and the opposite: patients who have less motor ability tend to be more dependent. The original construction of the complexity of the items according to the weight scheme in the K-B Scale (105, 106) was developed to be applicable for all people with or without a disorder and to be used by rehabilitation professionals. The complex items include items concerning survival (eating, taking care of bodily needs etc.) and being mobile. The statistical analysis in study III showed that grip function and not the original weight scheme is decisive with regard to item complexity for cervical SCI patients. The most difficult items for the cervically injured patients were those that include precision grips (manipulation). Furthermore, all three weight levels, simple, average complex and complex, in the K-B Scale include items that require grasp abilities – power grip or precision grip or a combination of both , using one and two-hand grasps. This makes weighting items somewhat obsolete and only creates complexity in scoring the items for cervical SCI patients (149). However, the weight scheme might be applicable for patients with other diseases or disorders who have the same problems in performing ADL as stated in the K-B Scale (105, 106). Since several studies (5, 6, 47, 52, 53) have suggested that arm and hand function seems to play a crucial role for ADL independence in cervical SCI patients, the guiding principle for item complexity should instead be reflected by the patient's choice of categories in the K-B Scale. In addition to letting the patient's views be taken into consideration in the assessment, this change in perspective also means an acknowledgment that the patient's perspective is more informative than the perspective of groups of health professionals (65).

Use of sum raw score in the K-B Scale

Sum score of ordinal data is common in ADL assessments (154) and it is used in the K-B ADL Scale in study III. The K-B ADL scale is considered to be an ordinal scale, which means that each successive score does not necessarily represent an equal amount of change (154). However, the use of a total score for degree of independence assumes that the items in the scale have equal disability values which lead to which leads to a questioning of the basic soundness of measures of disability (155). Only the analysis with raw sum score was useful in study III and it was used according to the recommendations in the K-B Scale (105, 106), even though it makes it more difficult to interpret the results since patients can have the same scores in spite of different needs of assistance (29). The level of measurement for ADL scales is identified as categorical assessments, which makes the use of sum score questionable and interpretations in study III should therefore be made with statistical caution (30). Today there exist other approaches (151, 156, 157) for analysing categorical assessments that better reflect the level of measurement than do the methods proposed in the K-B Scale.

CONCLUSION

The treatment regimens with an electric power driven wheelchair with a special armrest and FPL tenodesis have been shown to be suitable solutions for tetraplegic patients for them to gain full active elbow extension and a well balanced thumb. The most important effect of the electric power driven wheelchair and armrest is that they prevented shoulder adduction and therefore spared the proximal tendon graft from excessive elongation. The FPL tenodesis gives a pliable thumb with a more passive than active range of movement and thereby eliminated the need for arthrodesis of the IP joint in severely paralysed hands. The K-B Scale can be used to assess basic ADL with a raw sum score and discriminate cervical SCI patients' ability from less to greater independence in ADL. The analyses have however shown inherent problems with the weight scheme. To become a useful tool, the K-B Scale's structural properties, its categories and its operational criteria in the items must be further investigated. Furthermore, its reliability in conjunction with arm and grip function in patients with cervical SCI has yet to be proven.

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Reconstructive arm and hand surgery in patients with cervical spinal cord injury; Evaluation of postoperative treatments and examination of applicability of the Klein-Bell ADL Scale

Annika Dahlgren

ERRATA

Frame	p.18	the abbreviation NT in Figure 8 should be: *NT = Not tested*
	p. 23	Figure 2 in second last line should be: *Figure 10 The proportion of independent patients in 159 items divided into the dimensions of use of telephone, eating, mobility, hygiene, dressing and elimination in the Klein-Bell ADL Scale.*
	p.31	First paragraph, Line 12 "a more powerful design to investigate the effects of using the special armrest after reconstruction of elbow extension" should be: "a more powerful design to investigate the effects of using the *electric power driven wheelchair* and special armrest after reconstruction of elbow extension"
	p. 32	First paragraph, line 1 "Study III made no distinction between complete and incomplete patients compared to other studies" should be: "Study III made no distinction between complete and incomplete *injured* patients compared to other studies"
	p.38	Second paragraph, line 5 "have equal disability values which lead to which leads to a questioning of the basic soundness of measurement of disability" should be: "have equal disability values *which leads* to a questioning of the basic soundness of measurement of disability"
Reference	p. 45	116 Grimby G, Smaby B. Applying the ICF in medicine.2004 should be: *Stucki G, Grimby G. Applying the ICF in medicine. J Rehabil Med. 2004 Jul(44 Suppl):5-6.*
Paper II	p.98	Table III. Data are median (range) should be: *Mean (SD)*
Paper III	p.480	Figure 5 Y-axis a description of the data should be: *"Independently performed items"*